

The University of Chicago

GEOLOGY AND PARAGENESIS
OF THE GOLD ORES OF THE HOWEY
MINE, RED LAKE, MINNESOTA

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

1936

By

WILLIAM BARDWELL MATHER

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GEOLOGY AND PARAGENESIS OF THE GOLD ORES OF THE HOWEY MINE, RED LAKE, ONTARIO.

W. B. MATHER.

INTRODUCTION.

RED LAKE lies in the Patricia portion of the Kenora District, Ontario, about forty miles northwest of Lac Seul (Goldpines). The Howey mine is located on the southwest shore of the south-east bay of Red Lake about one half mile west of Lornow Lake.

In 1893 the late D. B. Dowling visited the territory between the English and Berens Rivers; his report ¹ noted the sedimentary rocks occurring around Red Lake. In 1922 and 1923 the Ontario Department of Mines sent a field party to Red Lake under the direction of E. L. Bruce.² In 1926 a second party was sent into this area under the leadership of E. L. Bruce and J. E. Hawley,³ which undertook a more detailed study of the district. During the period of this later study the Howey property was undergoing its early development. In October, 1934, E. L. Bruce and the staff of the Howey mine published a complete description ⁴ of the operation and management of the mine, a description of the ore-body and a résumé of the geology.

The author is greatly indebted to Mr. Edward Futterer, Resident Manager and the Engineering Staff of the Howey mine for their many courtesies. To Edson S. Bastin and Albert Johannsen of the Department of Geology, University of Chicago, the writer wishes to express his appreciation for their valuable advice and criticism, so generously given.

¹ Dowling, D. B.: Can. Geol. Surv., vol. 2, pt. F.

² Bruce, E. L.: Ont. Dept. Mines Ann. Rept., vol. 33, pt. 4, 1924.

³ Bruce, E. L., and Hawley, J. E.: Ont. Dept. Mines Ann. Rept., vol. 36, pt. 3, 1927.

⁴ Can. Mining Jour., Oct., 1934.

GENERAL GEOLOGY.

The rocks outcropping on the Howey property are predominately intermediate and basic lavas and associated pyroclastics of Keewatin age, intruded by a portion of the porphyry masses that are typical of the area. According to Wright,⁵ the porphyry dikes have an *en échelon* arrangement to the north, and Bruce⁶ states they are Post-Timiskaming (Algoman) in age. The strike of the main dike in the Howey mine is N. 63° E. and the dip about 80° S. It varies in width from 60 to 300 feet, the widest portion being east and west of the shaft and below the 1100 foot level. The lavas and porphyry dikes are traversed by diorite and so called "lamprophyre" dikes.

The ore body occurs in a dike rock described by Bruce⁷ as quartz porphyry. In reality, however, it is a composite dike, consisting of at least three closely associated porphyry dikes of different ages. Two of them are known locally as "waxy porphyry" and "dark porphyry"—the author has termed the third "lighter tonalite porphyry."

Above the 1100 foot level the waxy porphyry is the predominating wall rock, darker tonalite porphyry increases below this depth. The lighter tonalite porphyry was positively identified only on the 1175 foot level.

Petrography of the Rocks on the Howey Property.

Bostonitic Andesite Porphyry or "Waxy Porphyry."—The bostonitic andesite porphyry is locally called "waxy porphyry" and is a fine-grained dike rock, megascopically light green in color and waxy in appearance. Thin sections show phenocrysts of sodic oligoclase. The rock has a bostonitic or haphazard texture and is composed of laths of plagioclase (sodic oligoclase) in a fine-grained groundmass of quartz, sodic oligoclase, accessory biotite (less than 1 per cent.) and magnetite. Sericite, carbonate, kaolin, chlorite and quartz are alteration products of the primary

⁵ Wright, D. G. H.: The Red Lake gold area. Eng. Min. Jour., p. 18, July, 1926.

⁶ Bruce, E. L., and Hawley, J. E.: *Op. cit.*, p. 3.

⁷ Idem: pp. 31-32.

minerals. Pyrite, quartz, chlorite and carbonate have been secondarily introduced.

Specimens from different parts of the mine have undergone different degrees of alteration, in many cases resulting in a schistose-cataclastic texture with only traces of the earlier porphyritic-bostonitic texture.

Lighter Tonalite Porphyry.—The lighter tonalite porphyry is a fine to medium-grained dark rock. The plagioclase phenocrysts have undergone crushing and recrystallization and are partially altered to sericite, carbonate and kaolin. The schistose matrix consists of feldspar, quartz, biotite and magnetite now partially altered to white mica, carbonate, kaolin and chlorite. Pyrite, quartz and carbonate have been introduced by hydrothermal solutions. The biotite has been bleached, and the feldspars have undergone more sericitization and carbonatization than those of the andesite porphyry. The original composition of the rock was probably about 60 per cent. quarfeloids and 40 per cent. biotite. The rock is a tonalite porphyry and differs from the andesite porphyry in that the latter contains a larger percentage of quarfeloids and less biotite. The andesite porphyry is less altered and has larger phenocrysts than the lighter tonalite porphyry. Sodic oligoclase forms the phenocrysts in the former and oligoclase in the latter.

Darker Tonalite Porphyry or "Dark Porphyry."—The darker tonalite porphyry, locally called "dark porphyry," consists of elongated "eyes" of quartz in a matrix of biotite with smaller amounts of plagioclase. Apatite, magnetite, zircon, carbonate, white mica, chlorite and pyrite occur in smaller amounts. The original composition of the rock was probably 60 per cent. biotite and 40 per cent. quarfeloids. The feldspar has been altered to sericite and kaolin, the biotite to chlorite, and the magnetite largely altered to leucoxene. The rock is now a biotite schist and originally was probably a melatonalite or darker tonalite porphyry. It differs from the lighter tonalite porphyry not only in color but in being finer-grained, more schistose and in containing more biotite and less quarfeloids. There is also a more or less parallel

arrangement of the pyrite whereas in the lighter tonalite porphyry the pyrite grains are scattered heterogeneously through the rock. In addition, the lighter tonalite porphyry does not contain the elongated "eyes" so characteristic of the darker tonalite porphyry.

Biotite Schist or "Lamprophyre."—A fine-grained, black dike rock locally called "lamprophyre" transects the various porphyries and varies from stringers to dikes a few feet wide. It was originally composed almost entirely of biotite, now partially bleached, and a few scattered grains of quartz. Sericite, quartz and carbonate have been secondarily introduced. The rock differs from the dark porphyries in being finer-grained and in consisting almost entirely of biotite. It is not a lamprophyre since it does not contain feldspar or dark phenocrysts and consists almost entirely of biotite; therefore either "glimmerite," suggested by Larsen and Pardee,⁸ or "biotitite," suggested by H. S. Washington,⁹ is a more suitable term. It is so highly altered that it may well be called a biotite schist.

Diorite.—Diorite is a coarse-grained intrusive rock occurring as a single dike in greenstone near the porphyry dikes. In thin sections it is found to consist of the following minerals: amphibole 60.0 per cent., quartz 1.0 per cent., oligoclase 25.0 per cent., epidote 8.0 per cent., magnetite 3.0 per cent., carbonate 2.0 per cent. and biotite 1.0 per cent. Pyroxene, pyrite and titanite are accessories.

Andesite or "Greenstone."—A specimen of greenstone, procured near the mine, is composed of large phenocrysts of oligoclase partially altered to kaolin; amphibole partially altered to chlorite, in a fine-grained groundmass of chloritized biotite; apatite, titanite and magnetite are accessory minerals; carbonate, quartz and pyrite are secondarily introduced. Flow texture indicates the extrusive character. The rock was originally an andesite.

⁸ Larsen, E. S., and Pardee, J. T.: The stock of alkaline rocks near Libby, Montana. Jour. Geol., vol. 37, p. 101, 1929.

⁹ Washington, H. S.: The itelite locality of Villa Senni. Am. Jour. Sci., vol. 14, pp. 187-189, 1927.

The Effect of the Porphyry Intrusion.—"Greenstone" specimens, procured about one half mile from the porphyry intrusion consist of chlorite, oligoclase and amphibole. Changes in the composition of the "greenstone" were observed at the immediate contact with the porphyry, where the country rock is composed of chlorite, sericite, oligoclase, quartz and biotite.

It is difficult to separate the effect of the porphyry intrusions from the later hydrothermal alterations. Chlorite is developed in the lavas of the whole area. Sericite is known to have been developed in the porphyry by the hydrothermal solutions; therefore it is probable that part of the sericite in the greenstone is derived from this source. The change in feldspar to a more sodic variety is probably due to the intrusion of the andesite porphyry, which contains sodic oligoclase. The development of biotite may be due to the alteration of the amphibole or to introduction during the intrusion of the tonalite porphyries, since the latter introduced biotite into the earlier andesite porphyry.

SEQUENCE OF EVENTS LEADING UP TO ORE DEPOSITION.

1. *Deposition of Keewatin lavas and pyroclastics on an unidentified terrain.*
2. *Intrusion of andesite porphyry into Keewatin lavas.*
3. *Fracturing of andesite porphyry and subsequent filling of the fractures by quartz and massive pyrite.* Proof of this fracturing was observed on many mine levels where quartz veins, traversing andesite porphyry, are sharply terminated by tonalite porphyry.

Additional evidence of the earlier age of the andesite porphyry was found on the 750-foot level. Here, at the contact between the andesite porphyry and darker tonalite porphyry, small apophyses of the latter are injected into the former. Similar occurrences were observed on other levels. On the 1175-foot level there is an andesite-lighter tonalite porphyry contact showing apophyses of the latter injected into the former.

Thin sections of a sharp boundary between the andesite and darker tonalite porphyries show the latter to be exceedingly fine-

grained at the contact (Fig. 2), becoming coarser-grained a short distance from it. In addition, the darker tonalite porphyry bulges around large feldspar phenocrysts projecting from the andesite porphyry. The andesite porphyry at the boundary has undergone sericitization and the introduction of a small amount of biotite, but shows no marked diminution of grain size.

4. *Intrusion of the lighter tonalite porphyry into the andesite porphyry.* As pointed out in the preceding discussion, apophyses of this rock occur in the andesite porphyry.

5. *Intrusion of darker tonalite porphyry.* As previously stated, apophyses of the darker tonalite porphyry transect the andesite porphyry and, in addition, dikes of the dark rock cut across large andesite porphyry masses.

Thin sections of the lighter-darker tonalite porphyry boundary show a chilled darker tonalite porphyry with a very fine grain at the contact, becoming coarser-grained at a short distance from it. In addition, the former has undergone more alteration than the latter rock. Similar evidence is found in thin sections of the andesite-darker tonalite porphyry contact proving definitely the later age of the darker tonalite porphyry. Except in a few cases the contacts between the various porphyries are very sharp.

6. *Fracturing of all the porphyry dikes and subsequent filling of the fractures by quartz.*—Before the “lamprophyric” intrusion there must have occurred a period of intense fracturing and brecciation since the porphyries all appear more highly shattered than the later “lamprophyres.”

7. *Intrusion of “lamprophyre” dikes which transact the various porphyries.*

8. *Period of faulting; quartz and pyrite crystallizing in the fractures.* In the roof of the 750 east level a “lamprophyre” dike has been cut off by a fault, the break now occupied by a barren quartz vein 18 inches in width. Other instances of a similar nature were observed in many places.

9. *Another period of fracturing, largely of the tensional type; the fractures were subsequently filled by the ore minerals.*

ORE DEPOSIT.

The Ore Body.

The Howey ore body (Fig. 1) is a lode deposit, approximately 1000 feet long and the width increasing from 50 feet at the sur-

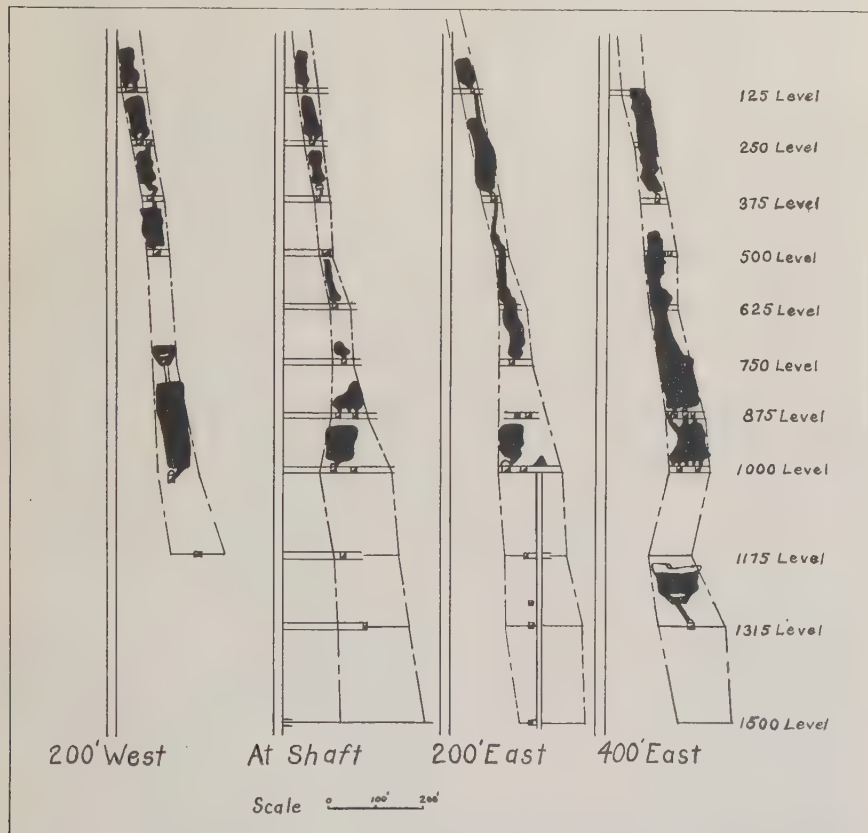
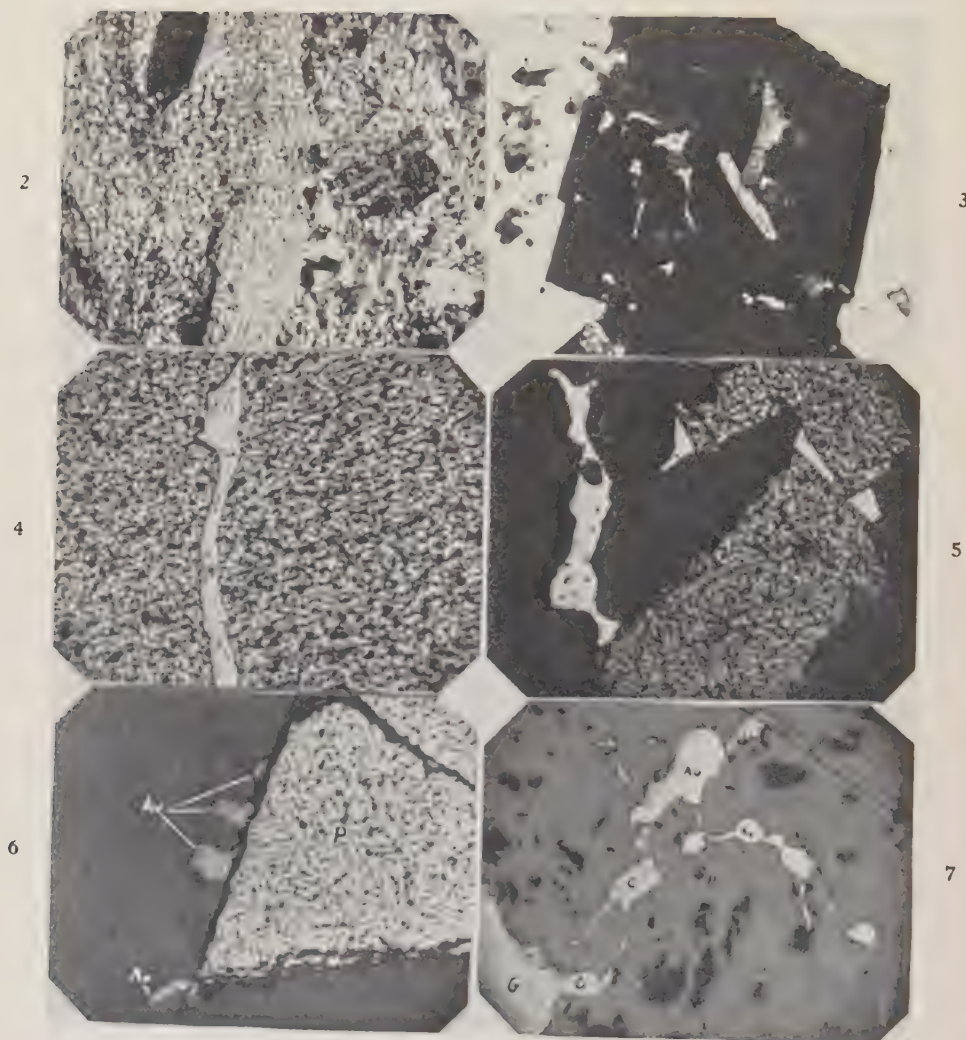


FIG. 1. Vertical cross-section of the Howey gold mine showing boundaries of the porphyry masses (broken lines) and the mined ore (black).

face to 175 feet on the 1500-foot level. It is dike-like in form, forming a portion of one of the porphyry masses that intrude the greenstone of the area, and consisting of a mass of lenticular



FIGS. 2-7.

sheet-like quartz-tourmaline-carbonate veins. Those bearing gold are mostly less than 6 inches wide.

The vein system appears complex and the author's findings are in accordance with those of Bruce and Hawley¹⁰ who state that

The strike of most of the veins is at an angle of approximately 20° S. of that of the main porphyry mass, which trends at N. 63° E. Some veins strike with the porphyry, others lie at about N. 17° W. and minor ones have various alignments. The most prominent fractures lie nearly parallel with the direction of the porphyry. In general, the veins are lenticular sheets filling fractures, nearly vertical or dipping with the porphyry steeply south. . . . The shearing of the relatively brittle porphyry mass caused the fractures of both tensional and shear origin. Into these, principally the former type, came quartz and various sulphides. . . .

The porphyry mass, in which the ore body is located, is a composite dike and was formed, preceding the ore deposition, by three separate intrusions along the same zone of weakness. The localization of the ore body is attributed to the greater abundance of "waxy porphyry" and earlier quartz veins, which are more easily and more cleanly fractured than the "greenstone," "lamprophyre" and darker porphyries. It is therefore the zone of greatest weakness and most severe fracturing.

The average ore value is \$2.75 per ton.

¹⁰ *Op. cit.*: Ont. Dept. Mines Ann. Rept., vol. 36, pt. 3, pp. 59-61.

FIG. 2. Contact of bostonitic andesite porphyry (waxy porphyry) and darker tonalite porphyry (dark porphyry). The former is coarser grained and contains a feldspar phenocryst while the latter has a chilled contact and is composed of small sericite grains. X-nicols. X 40.

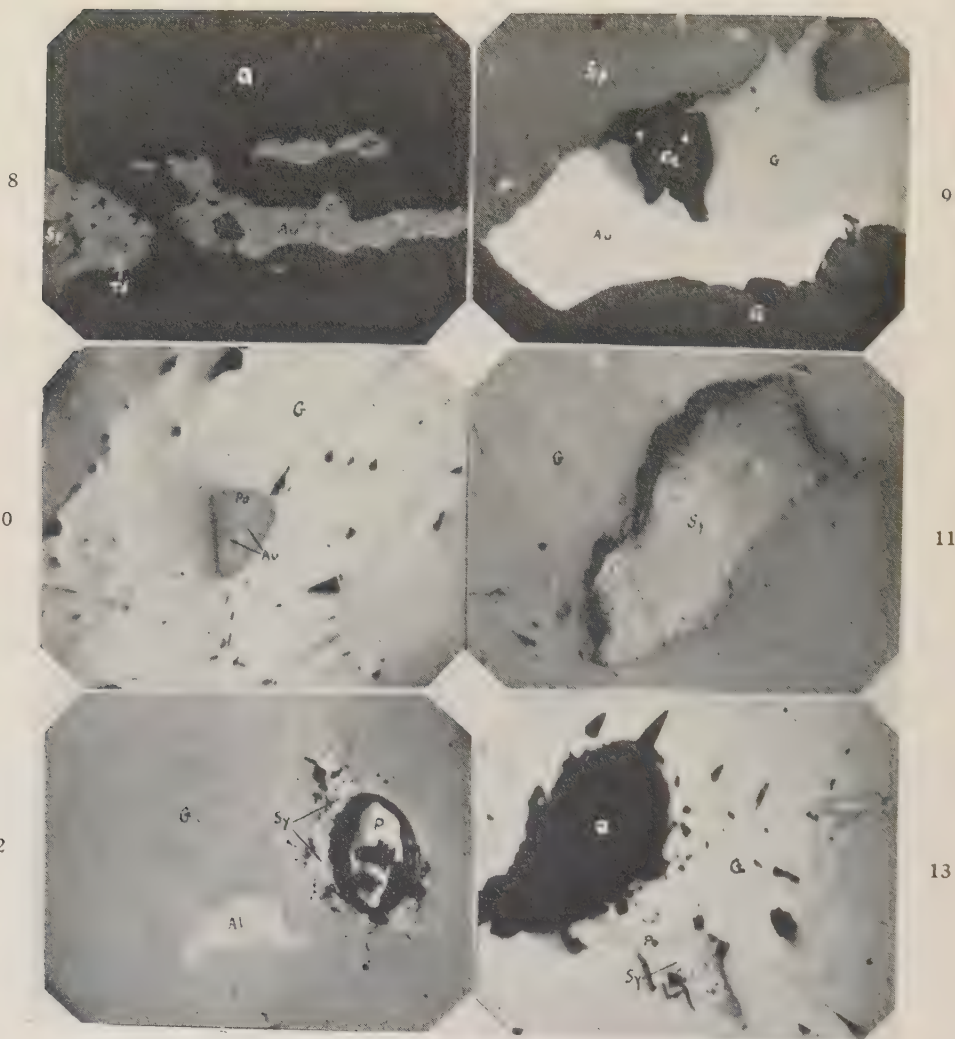
FIG. 3. Automorphic tourmaline laths (gray) in pyrite cube (black). Quartz is white. X 70.

FIG. 4. Free gold (light gray) replacing and filling a fracture in pyrite (mottled). X 80.

FIG. 5. Interstitial free gold (white) and pyrite cubes (mottled) in quartz (black). X 63.

FIG. 6. Free gold (Au) occurring at contact of pyrite (P) and quartz (dark gray) and replacing the latter. X 63.

FIG. 7. Gold (Au) and chalcopyrite (C) as blebs in sphalerite (Sp). Chalcopyrite intergrown with galena (G). X 100.



FIGS. 8-13.

Mineralogy.

This subject includes both a description of the occurrence and appearance of the metallic and non-metallic minerals that constitute the ores. The metallic minerals were definitely identified by their physical and optical properties and their reaction to various etching reagents as described by Short¹¹ and also by microchemical tests as outlined by Chamot and Mason.¹²

Pyrite (Figs. 3, 4, 5, 6), one of the earliest of the ore minerals to crystallize, is the most abundant metallic mineral in the ores. It is also found in all rocks associated with the ores. Its age in the wall rocks can not be ascertained with certainty. It is known to have accompanied quartz at each period of fracturing and subsequent fracture-filling; a possible exception is that which followed the introduction of gold and its associated minerals.

Free gold (Figs. 4, 5, 6, 7, 8, 9) occurs generally in a finely divided state, and is megascopically visible in only four hand specimens. Under the microscope it was identified in four fifths of all specimens examined. In polished section the color varies from golden to pale yellow. Van der Veen¹³ states that the pale color of certain free gold is due to the silver it contains in

¹¹ Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 825, 1931.

¹² Chamot and Mason: Handbook of Chemical Microscopy. John Wiley and Sons, New York, vol. 2, 1931.

¹³ Van der Veen, R. W.: Mineragraphy and ore deposition. The Hague, p. 106, 1925.

FIG. 8. Free gold (Au) and chalcopyrite (C) forming a veinlet in quartz (Q). Blebs of tetradymite (Td) and sphalerite (Sp) in chalcopyrite. $\times 80$.

FIG. 9. Free gold (Au) intergrown with carbonate (Ca), galena (G), sphalerite (Sp) and quartz (Q). $\times 100$.

FIG. 10. Polybasite (Po), containing small free gold (Au) inclusions in galena (G). $\times 100$.

FIG. 11. Sylvanite (Sy) inclusion in galena (G). $\times 100$.

FIG. 12. Altaite (Al), sylvanite (Sy) and pyrite (P) in galena (G). $\times 100$.

FIG. 13. Polybasite (Po) intergrown with sylvanite (Sy) and forming inclusions in galena (G). Non-metallic is quartz (Q). $\times 110$.

solid solution; this is verified by the occurrence of the pale yellow type as blebs in polybasite (Fig. 10). Microchemical tests show that the amount of silver present is insufficient to form electrum. The difference in color and therefore in composition can be correlated with difference in age; the golden yellow type is older and the pale yellow is younger.

Sylvanite, tetradymite, aikinite, polybasite and free gold are closely associated, the latter commonly occurring as an inclusion in the others. Carbonate is the predominant contemporaneous gangue mineral, although in many cases quartz contains isolated blebs of free gold.

Chalcopyrite (Figs. 7, 8) is indicative of high gold values, and is generally associated with galena and sphalerite, but specimens from the 500-foot stope consist almost entirely of chalcopyrite, free gold, pyrite, tetradymite, aikinite, galenobismuthinite and a small amount of sphalerite.

Galena (Figs. 9, 10, 11, 12, 13) is also considered indicative of high gold values and is mostly associated with the tellurides, sphalerite, chalcopyrite and free gold. In hand specimens it is seen as irregular masses in fractured quartz, but thin sections and polished surfaces show that it also occurs with tourmaline. If veinlets of tourmaline are traced, they eventually pass into quartz-carbonate veinlets containing galena, chalcopyrite and sphalerite.

Sphalerite (Fig. 7) is one of the most abundant of the metallic minerals and, in mining, is considered an indication of high gold values. In the Howey ore body it is of the lighter-colored resinous type, in spite of the fact that it was deposited in the presence of iron under hypothermal conditions. Polished sections show that it varies in hardness, in different crystal directions, which produces an appearance similar to the polysynthetic twinning in feldspar. Quartz is the predominant contemporaneous gangue mineral.

Cubanite (Fig. 14) occurs as long laths in specimens of chalcopyrite from the 1300-foot stope.

Pyrrhotite occurs almost exclusively in sphalerite but occasionally in chalcopyrite.

Arsenopyrite is found in specimens from all parts of the mine, but is especially abundant in those from the east 750-foot level. It commonly occurs along sphalerite-quartz contacts, showing automorphic contacts against quartz and mutual boundaries with sphalerite.

Löllingite occurs along quartz-sphalerite contacts similar to arsenopyrite.

Tetrahedrite occurs as automorphic inclusions or as irregular-shaped interstitial masses in sphalerite.

Polybasite (Figs. 10, 13) occurs almost entirely as inclusions in galena, which are generally composed of an intergrowth with either sylvanite or tetradymite. Inclusions of polybasite commonly contain blebs of the lighter-colored silver-bearing free gold. The shape of the inclusions vary from lath-like to irregular.

Sylvanite (Figs. 11, 13) is invariably associated with galena, generally possesses a lath-like or irregular form, and commonly occurs in galena inclusions in sphalerite or as lath-shaped grains that project from galena into sphalerite. It is commonly intergrown with a small amount of chalcopryrite, free gold, polybasite or tetradymite as an inclusion in galena.

Altaite (Fig. 12) occurs only in galena where it is found as small irregular-shaped masses, rarely intergrown with the other tellurides or polybasite and is closely associated with free gold.

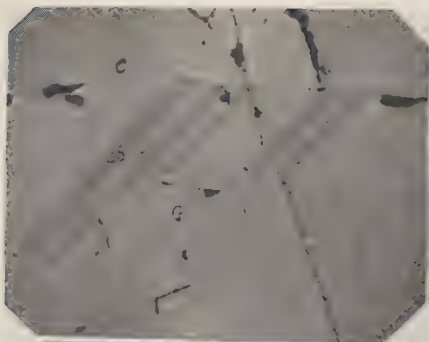
Tetradymite (Fig. 15), intergrown with galenobismuthinite, aikinite, chalcopryrite and free gold, is characteristic of ore from the 500-foot stope. It commonly occurs in galena as lath-shaped inclusions where it is intergrown with polybasite or sylvanite and closely associated with free gold.

Galenobismuthinite (Fig. 15) is almost invariably intergrown with tetradymite, aikinite, chalcopryrite and free gold.

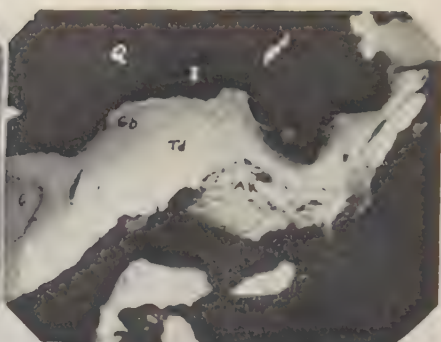
Aikinite (Fig. 15) is intimately intergrown with galenobismuthinite, tetradymite, chalcopryrite and free gold.

Ilmenite occurs as thin platy, dark steel-gray crystals in a specimen from the 1300-foot stope. Specularite is the only metallic mineral associated with it. It is embedded in ankerite,

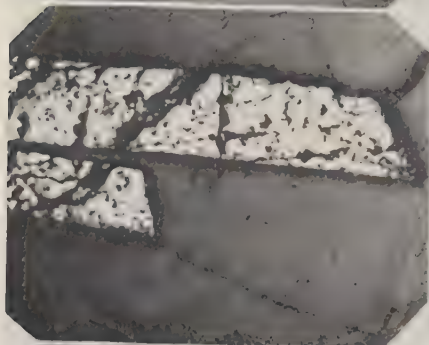
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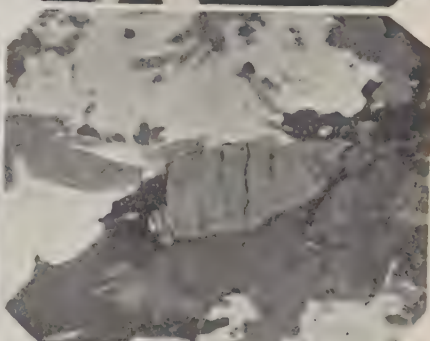
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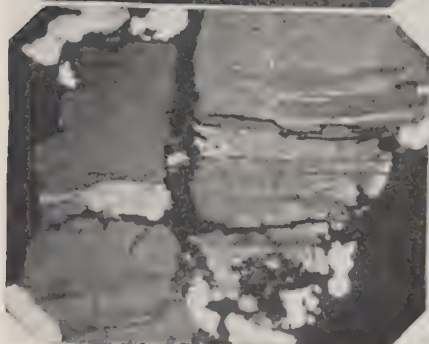
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17



18



19



FIGS. 14-19.

which is the most abundant non-metallic mineral occurring in the later stages of mineralization. (Fig. 16.)

Specularite occurs as platy, dark steel-gray inclusions in ilmenite or intergrown with carbonate forming small veinlets in ilmenite. It is only found associated with ilmenite and carbonate.

Rutile occurs as thin, dark metallic needles in ankerite. The only other minerals found associated with it are small amounts of quartz and muscovite. Its occurrence is similar to that of ilmenite and specularite.

Tourmaline (Figs. 3, 17) occurs as isolated, automorphic, dark bluish-gray prismatic grains or as large aggregates of intergrown smaller grains. In the Howey mine it is indicative of pay ore, and narrow veinlets consisting of solid tourmaline, if followed along the walls of the mine-workings, eventually pass into quartz and carbonate veinlets containing ore. Tourmaline was never observed replacing the wall rocks. Its most characteristic occurrence is at the outer edge of the veins where it forms knife-like boundaries between vein and country rock. The center of these veins consists of quartz, oligoclase, carbonate, white mica and the metallic minerals. Their dip varies from vertical to horizontal. They cut all wall rocks alike from the earlier barren quartz veins and highly silicified porphyry to lamprophyre dikes, but are especially abundant in the andesite porphyry.

Quartz developed as fracture-filling at various times during the early geologic history of this area, but the present discussion is concerned only with that part which crystallized from the ore-bearing solutions. It is the most abundant gangue mineral, and occurs in two generations. The later one fills fractures in the

FIG. 14. Cubanite (Cb) laths in chalcopyrite (C) and projecting to chalcopyrite-galena (G) contact. $\times 85$.

FIG. 15. Aikinite (Ak), tetradymite (Td), galenobismuthinite (Gb) and chalcopyrite (C) in quartz (Q). $\times 80$.

FIG. 16. Ilmenite laths (white) in carbonate (dark gray). $\times 40$.

FIG. 17. Ore minerals (black) filling fractures in tourmaline (darker gray) and also interstitial in tourmaline. Quartz is lighter gray. $\times 45$.

FIG. 18. Ore minerals (black) filling fractures in vein feldspar (gray). Quartz is white. $\times$ -nicols. $\times 20$.

FIG. 19. Pyrite (white) veinlet in sphalerite (dark gray). $\times 108$.

main metallic minerals and early quartz, tourmaline and early carbonate and is contemporaneous with later carbonate, ilmenite, specularite and rutile. The earlier generation, however, is more closely associated with the crystallization of the main ore-bearing minerals. In thin sections it is characterized by a comb-structure, mortar texture, sutured contacts between grains, undulatory extinction, and sharp contacts with the wall rocks. Therefore it is a fracture-filling and crystallized under stress, so intense that the contacts of many grains were granulated. The secondary quartz in the wall rocks is believed to have been derived from the breaking down of the silicate minerals in the wall rocks and from earlier siliceous solutions.

Quartz contains large areas of metallic minerals joined by small sulphide stringers, which are believed to have formed by their expulsion from the former as it crystallized, and therefore the sulphides were contained in the residual solutions and their crystallization was controlled by the crystal boundaries of quartz.

Oligoclase (Fig. 18), that occurs in the ore-bearing veins, is of the more sodic type. Quartz and oligoclase started crystallizing at the same time, but the former continued longer than the latter.

Carbonate occurs in two generations in the ore-bearing veins, one before and the other following the second period of fracturing. The later generation, which consists of predominant ankerite with small amounts of calcite, fills fractures that transect main ore-bearing veins. It is accompanied by small amounts of quartz, muscovite, ilmenite, specularite and rutile. The earlier generation consists of predominant calcite and a small amount of ankerite. Carbonate, like the metallic minerals, was expelled from the quartz-bearing solutions as the latter crystallized and therefore its crystallization was generally controlled by the crystal boundaries of quartz. As crystallization of the ore minerals progressed the amount of carbonate relative to quartz increased so that it became the main gangue mineral toward the end of the period of mineralization. The composition also changed from one high in calcium to one conspicuous for its magnesium and iron content.

White mica includes the shredded form generally called sericite, which is intergrown with the main ore minerals and books of muscovite associated with ankerite and ilmenite. The muscovite occurs along the walls of the ankerite veins, but the sericite is intergrown with the ore minerals that fill fractures in oligoclase or occurs along the crystal boundaries of quartz. Except for the fact that it is not intergrown with tourmaline and oligoclase, white mica is practically the same age as carbonate, sericite occurring with calcite and muscovite with ankerite. With the exception of chloritized biotite, it is the least abundant of the gangue minerals.

Chloritized biotite was only found in a few thin sections and is intergrown with chalcopyrite and galena as a fracture-filling in oligoclase.

Hydrothermal Alteration.

Quartz, sericite, carbonate and pyrite have been secondarily developed in the wall rocks. Part of the secondary quartz and carbonate was undoubtedly produced by the breaking down of the feldspars, by the fracture-filling solutions of an earlier period not accompanied by ore formation. This is proven by the more or less gradational contacts between large barren quartz veins, which are older than the ore-bearing veins, and the wall rocks. Sericite (or white mica), which is abundantly developed in all the wall rocks, has been produced by the disintegration of feldspar and also by the leaching of biotite. It is believed that part of it can be attributed to the ore-bearing solutions. Pyrite occurs most abundantly in the older barren quartz veins, which are believed to be the source of most of the pyrite in the wall rocks.

Thin sections of ore-bearing tourmaline-quartz and quartz-carbonate veins show conclusively that there has been only a small amount of replacement of the bordering wall rocks because the contacts are sharp and straight and also show no marked increase in the quantity of the secondary constituents in the wall rocks adjoining the ore-bearing vein. In addition, thin sections of gold pyrite veins have sharp straight contacts and show no replacement of the wall rocks.

CONCLUSIONS ON PARAGENESIS OF THE ORES.

Paragenesis Table.

The paragenetic sequence is broken into three stages by two episodes of fracturing. The first and second stages are separated by an episode of very weak fracturing which in thin and polished sections, is represented by small fractures in tourmaline (Fig. 17), quartz, oligoclase (Fig. 18) and pyrite (Fig. 4) that are filled by the later metallic and gangue minerals. The second and third periods are separated by an episode of stronger fracturing that is observed in hand specimens where ankerite-quartz veins cut

	Weak fracturing	Stronger fracturing
1. Pyrite	—————	----
2. Sphalerite	—————	
3. Free Gold	—————	
4. Galena	—————	
5. Chalcopyrite	—————	
6. Arsenopyrite		—
7. Pyrrhotite		—
8. Löllingite		—
9. Tetrahedrite		—
10. Sylvanite		—————
11. Tetradymite		—————
12. Altaite		—————
13. Polybasite		—————
14. Galenobismuthinite		—————
15. Aikinite		—————
16. Cubanite		—————
17. Ilmenite		———
18. Specularite		———
19. Rutile		----
20. Tourmaline	—————	
21. Quartz	—————	———
22. Oligoclase	—————	
23. Carbonate—chiefly calcite		—————
24. Carbonate—chiefly ankerite		—————
25. White mica—sericite		-----
26. White mica—muscovite		———
27. Chloritized biotite		-----

tourmaline-quartz veins. Small fractures in galena, filled with carbonate, chalcopyrite and cubanite and small fractures in sphalerite filled with pyrite (Fig. 19), may have formed at this time. The second period of mineralization is the most important because it includes all the valuable ore minerals.

Discussion of Paragenesis Table.

Tourmaline commonly has automorphic contacts against the other early minerals (Figs. 3, 17) and was, therefore, the first mineral to begin its crystallization. In thin section, tourmaline crystals are seen to be fractured and the fractures are filled with some of the ore minerals (Fig. 17) and carbonate but in the same section part of the tourmaline occurs as automorphic grains embedded in the same metallic minerals and carbonate. Therefore, tourmaline continued to crystallize after the first episode of fracturing and also overlapped the crystallization of part of the ore minerals.

Oligoclase and the first generation of quartz and pyrite have xenomorphic, automorphic or mutual boundaries with one another and, like tourmaline, they are either intergrown with carbonate and the metallic minerals or have fractures filled by them (Figs. 4, 18). Since they have mutual boundaries with sphalerite and commonly contain automorphic inclusions of free gold and more rarely of chalcopyrite and galena they therefore continued to crystallize for a short time in the second stage of mineralization. Small, straight, narrow veinlets of pyrite in sphalerite are proof of a second generation of pyrite (Fig. 19). Since they do not occur in chalcopyrite and galena, it is believed that they crystallized shortly after sphalerite had completed its crystallization. A second generation of quartz occurs in the third stage of mineralization where it is intergrown with ankerite and rutile.

Sphalerite commonly occurs as automorphic inclusions in pyrite or fills fractures in it and is mutually intergrown with quartz, arsenopyrite and löllingite. It contains automorphic inclusions and interstitial masses of galena, chalcopyrite, free gold, tetra-

hedrite and pyrrhotite (Fig. 7). It is, therefore, believed to have been the next mineral to begin crystallization.

Free gold, chalcopyrite, galena and carbonate occur as automorphic inclusions and interstitial masses in pyrite, quartz and sphalerite; therefore they started their crystallization soon after sphalerite and overlapping pyrite.

Arsenopyrite and löllingite have mutual boundaries against sphalerite and in one case against chalcopyrite. They are mutually intergrown with irregular masses of pyrite along sphalerite-quartz boundaries but are not found as inclusions in cubes of the latter mineral. Therefore, they are believed to be contemporaneous with the later stages of the first generation of pyrite, which is represented by irregular masses of pyrite that occur along quartz-sphalerite boundaries.

Tetrahedrite occurs as inclusions or interstitial grains in sphalerite and its absence in pyrite and automorphic boundaries against chalcopyrite suggest that it crystallized later than the pyrite and earlier than the main part of the chalcopyrite.

Pyrrhotite, like tetrahedrite, occurs as inclusions in sphalerite or as automorphic grains in chalcopyrite and is therefore believed to be the same age as tetrahedrite.

Sylvanite occurs as automorphic or irregular inclusions in large masses of galena (Fig. 11) or in galena inclusions in sphalerite. Since it is not found in pyrite, its crystallization is later than that mineral but overlaps the crystallization of sphalerite.

Tetradymite and polybasite are intergrown with sylvanite (Fig. 13) and also occur as isolated automorphic or irregular-shaped inclusions in galena. They are not found in galena inclusions in sphalerite and, therefore, began crystallizing later than the latter mineral and completed their crystallization before galena.

Galenobismuthinite and aikinite are mutually intergrown with tetradymite and chalcopyrite (Fig. 15) and are therefore the same age as tetradymite.

Since altaite mostly occurs as irregular-shaped inclusions (Fig. 12) or as interstitial grains in galena it is believed to have crystallized during the later part of the galena crystallization.

Cubanite laths occur in chalcopyrite (Fig. 14) that is mutually intergrown with galena and in chalcopyrite inclusions in sphalerite. Therefore, its crystallization overlaps that of sphalerite. It is also intergrown with chalcopyrite and carbonate in small replacement veinlets along cleavage fractures in galena and therefore, like carbonate and chalcopyrite, continued its crystallization after galena.

Carbonate (chiefly calcite) is mutually intergrown with galena, chalcopyrite and free gold and therefore has the same age relations as these minerals. Carbonate (chiefly ankerite) is the dominant mineral in the third stage of mineralization and has xenomorphic contacts against ilmenite, specularite and rutile.

Sericite and chloritized biotite are intergrown with thin stringers of chalcopyrite and galena in quartz, but their age is uncertain.

Muscovite occurs as automorphic grains in the carbonate of the third period of the mineralization.

THE ORE-BEARING SOLUTIONS.

Composition.—Changes in the composition of the depositing solutions appear to have occurred at the termination of the first and second stages of mineralization. The solutions of the first stage contained the following compounds and ions, either free or combined in various combinations, SiO_2 , Al, Na, Ca, Fe, B, F and H_2S . The solutions of the second stage contained Pb, Au, Cu, Bi, Te, Ag, Fe, Zn, Ca, Mg, SiO_2 , H_2O , H_2S , As, Sb and CO_2 . The third stage was characterized by the precipitation of Ti, Fe, Ca, Mg, SiO_2 , H_2O and CO_2 .

Temperature.—The diagnostic minerals are tourmaline, oligoclase, pyrrhotite, muscovite, ilmenite, rutile and specularite. The first three occur during the first stage and early part of the second stage of mineralization and the last four during the last portion of the mineralization. These minerals are all indicative of high temperatures and pressures. Therefore, the ores are considered hypothermal. Tetrahedrite is generally considered mesothermal but the fact that it is contemporaneous with several definitely hy-

pothermal minerals suggests that it crystallized here under high temperature and pressure conditions.

Source.—The source of the gold-bearing solutions can, at best, be only conjectured. It is probable that the late fracturing of the porphyry dikes is due to the intrusion of a nearby igneous mass which could also have supplied the gold-bearing solutions. The nearest igneous mass, younger in age than the porphyry dikes is a granite massif which lies to the north of the Howey mine and, since gold-bearing veins have been found on the periphery of this granite; it may have been the source of the ore solutions that formed the Howey ores.

SUMMARY.

The Howey ore body is located in a series of dikes that are intrusive into the Keewatin lavas of the Red Lake area. A bas-tonitic andesite porphyry, the most acidic of the dike rocks, was intruded first. This was subsequently fractured and the fractures were filled with quartz. The second intrusion, a lighter tonalite porphyry, and the third intrusion, a darker tonalite porphyry, show a progressive increase in biotite and decrease in quartz content. Between the intrusion of the latter two dike types there may have been a period of fracturing and fracture-filling; all that is definitely known is that the andesite porphyry was fractured before the darker tonalite intrusion. Following the intrusion of the latter there was a period of fracturing and brecciation, and the fractures were filled with quartz and pyrite. The last dike intrusion, locally called "lamprophyre," is the most basic of all, and consists almost entirely of biotite. A period of intense fracturing and brecciation followed this intrusion, and the fractures were again filled by quartz and pyrite. These fracture-filling solutions caused silicification, sericitization and pyritization of the wall rocks. At this stage it is believed that an adjacent granite mass (McKenzie Island batholith) had begun to cool, therefore to shrink, thus relieving the pressure in the surrounding rocks and producing fractures that were filled by the residual liquid from the granite. The occurrence in the veins of such common magmatic minerals as oligoclase, rutile, ilmenite and specularite, the common pneumatolytic minerals, tourmaline and muscovite,

and the usual hypothermal mineral pyrrhotite suggests that the nearby granite was the probable source of the ore-solutions.

Evidence that the veins were formed by fracture-filling and not by replacement is offered by the following facts: (1) The veins are lenticular in shape. (2) They have straight, knife-edge contacts against the wall rocks. (3) The tourmaline-quartz-pyrite veins are slightly banded. Tourmaline lines the walls, pyrite next and the center is filled with quartz, oligoclase and a small amount of carbonate. (4) In thin sections vein quartz has a conspicuous comb-structure.

The mineralization was probably a continuous process but is divisible into three episodes or stages, each separated by an episode of fracturing. The earliest minerals to crystallize—tourmaline, oligoclase, pyrite and quartz—were fractured during their crystallization, and this fracturing terminated the first stage of mineralization. These minerals continued to crystallize during the early part of the second stage of mineralization, which is characterized also by the crystallization of pyrrhotite, löllingite, arsenopyrite, sphalerite and tetrahedrite. The crystallization of free gold, galena, chalcopyrite, cubanite, sylvanite, tetradymite, altaite, polybasite, galenobismuthinite, aikinite and carbonate occurred at various times during this second stage of mineralization which also ended with fracturing. The third stage of the mineralization resulted in the crystallization of ilmenite, specularite and rutile in a gangue of predominant ankerite and smaller amounts of quartz, muscovite and calcite.

The composition of the carbonate and its importance as a gangue mineral changed during the process of mineralization. In the early part of the second stage of mineralization it was calcite but it was unimportant in amount. As mineralization progressed the amount of calcium decreased while magnesium and iron increased and the carbonate as a whole gradually supplanted quartz as the chief gangue mineral, with the result that in the third stage of mineralization the gangue consists almost entirely of ankerite.

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